



Technology developments toward sub-arc-second x-ray optics

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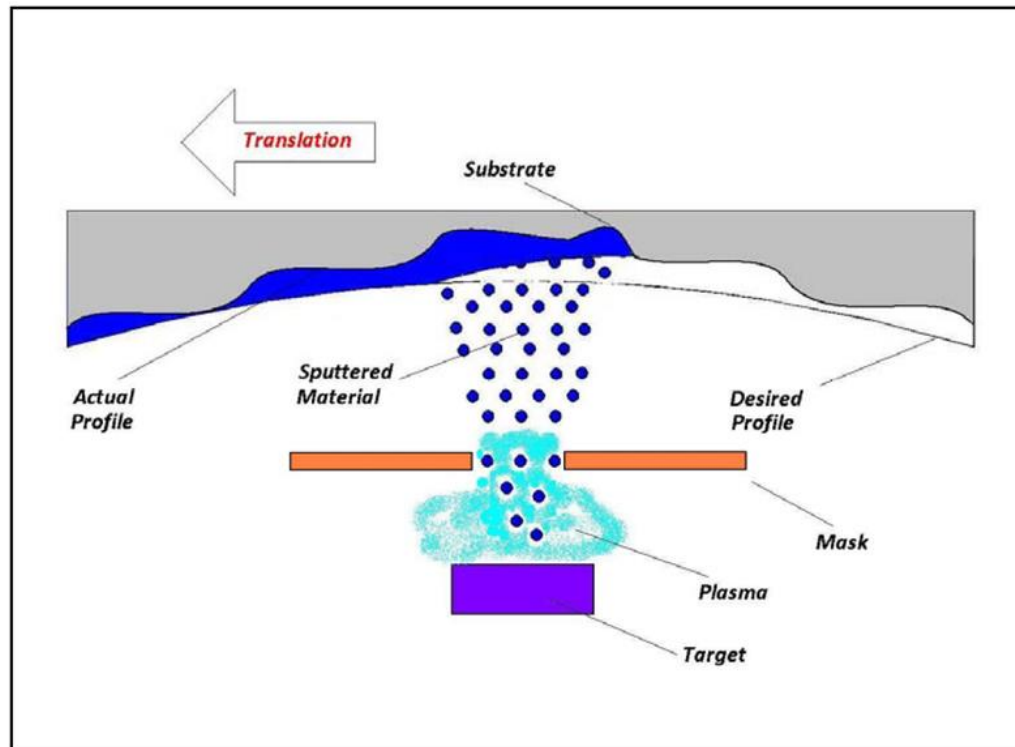
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Differential Deposition

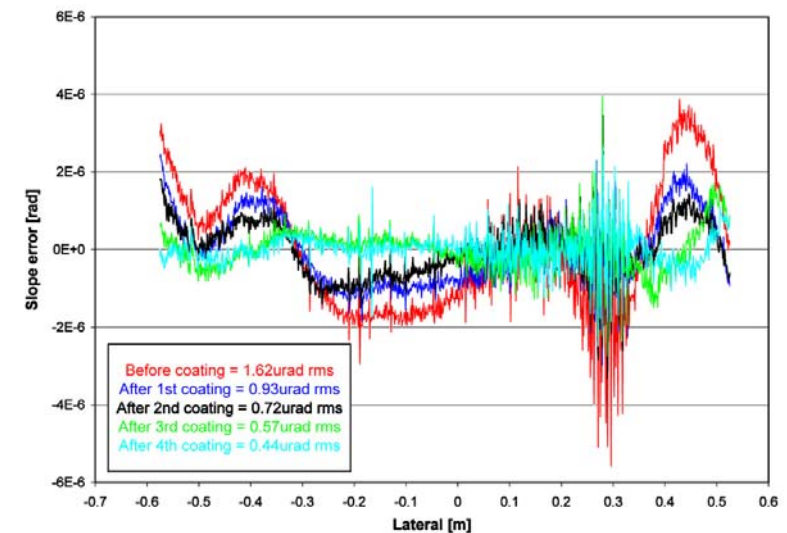
Challenge is to control the figure errors for spatial scale range between 0.5 mm to 0.5 m

Figure correction - Differential Deposition



Advantages:

- Covers the full spatial scale range.
- Applicable to full shell and segmented optics
- Can be used to correct the surface deformations due to mounting and assembly
- Technique is used for synchrotron optics

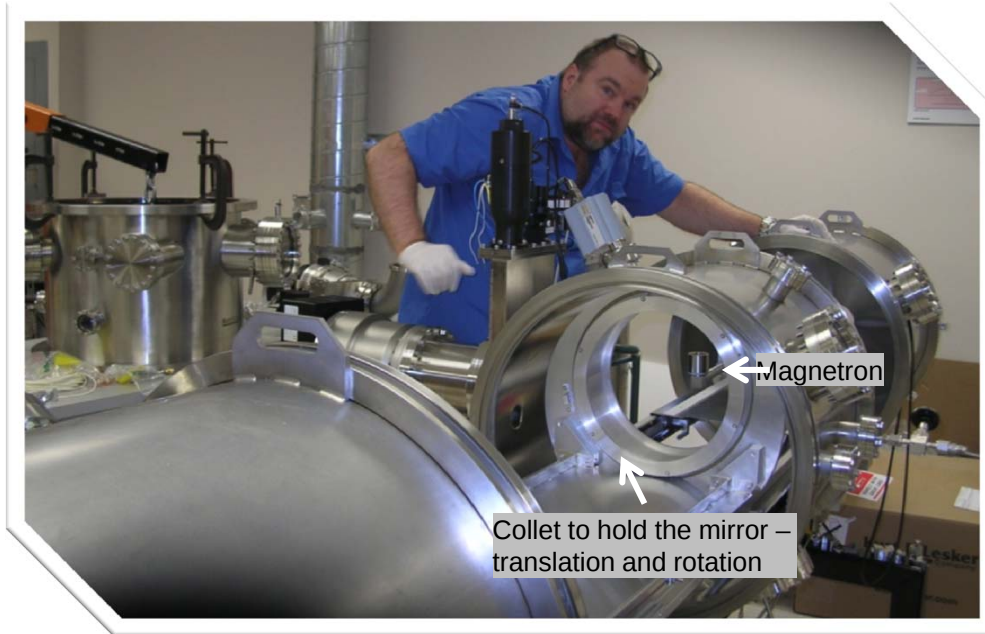


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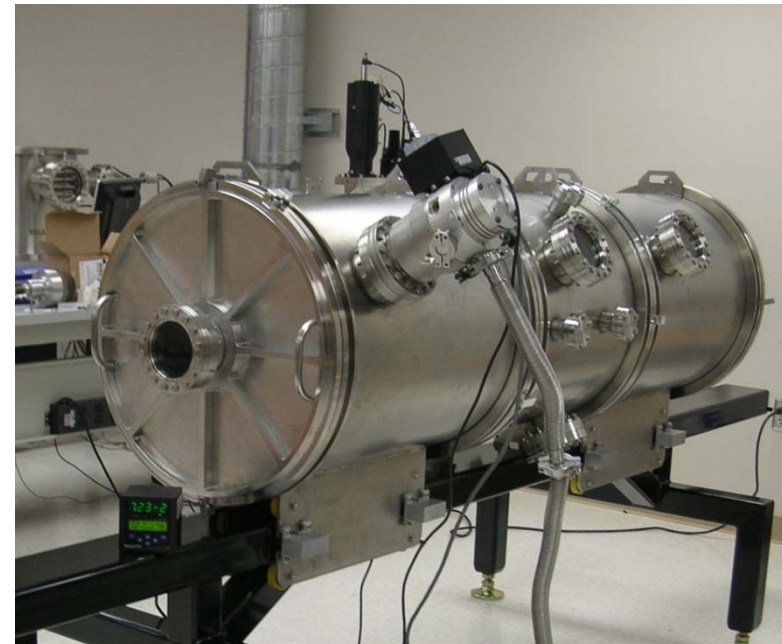
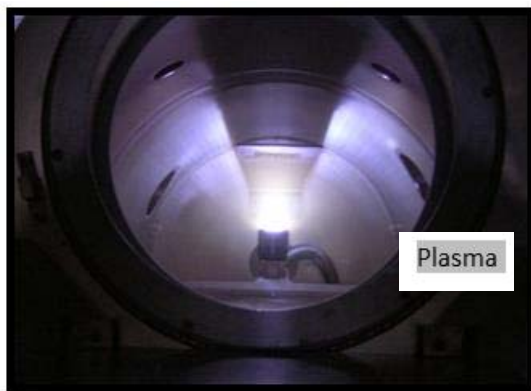
A preferential coating technique for fabricating large, high quality optics S.G. Alcock, S. Cockerton, NIM A 616, 2010



Differential Deposition



- Proof of concept on miniature optics completed.
- Chambers for full scale optics are just being commissioned (coating rates, beam profiles etc).
- Expect to be coating shells in a few weeks (both full shells and segmented optics). We can accommodate up to 50 cm diameter full shells, but we will start with 15 cm ones



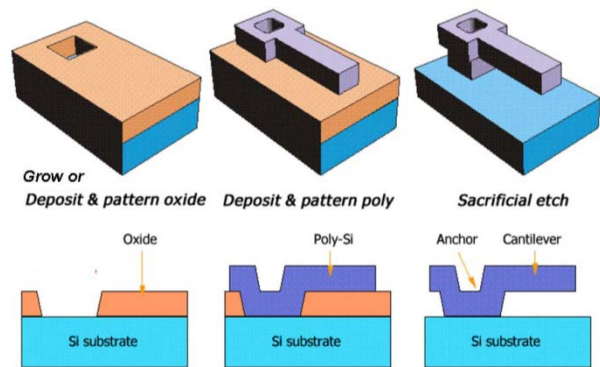


Stress Measurement in Coatings

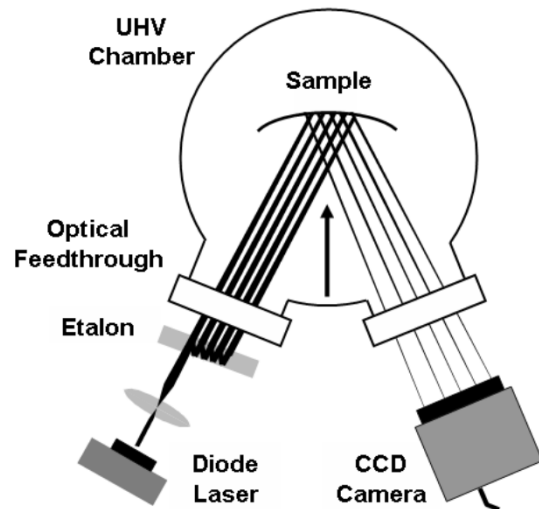


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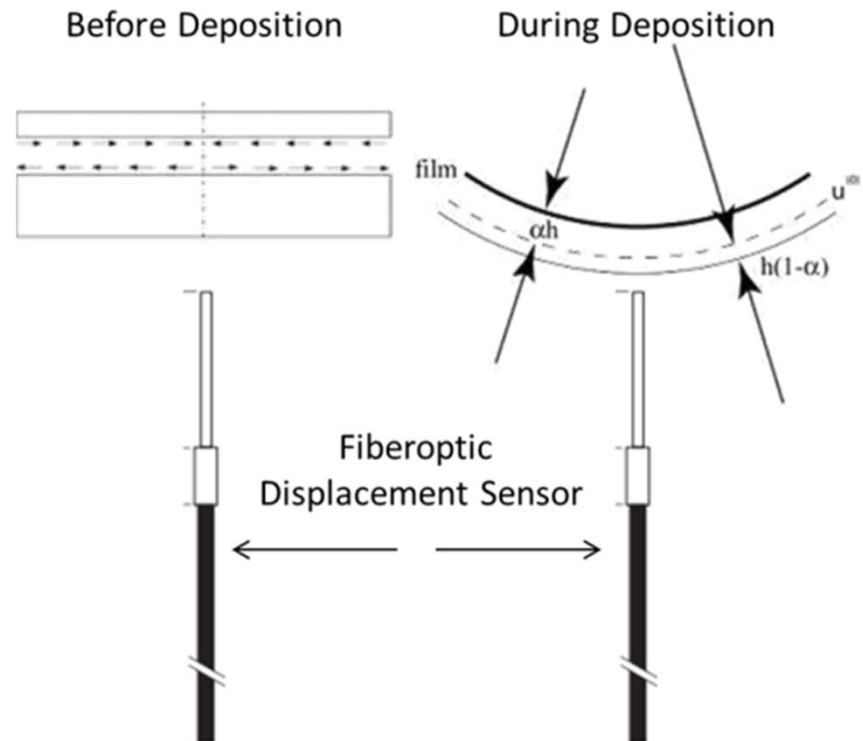
Micro Cantilever



Multi-Beam Array



Our Method: We exploit the known spherical deformation due to stress and calculate the substrate curvature by measuring the sag of the coated wafer (just one point).





Film Stress

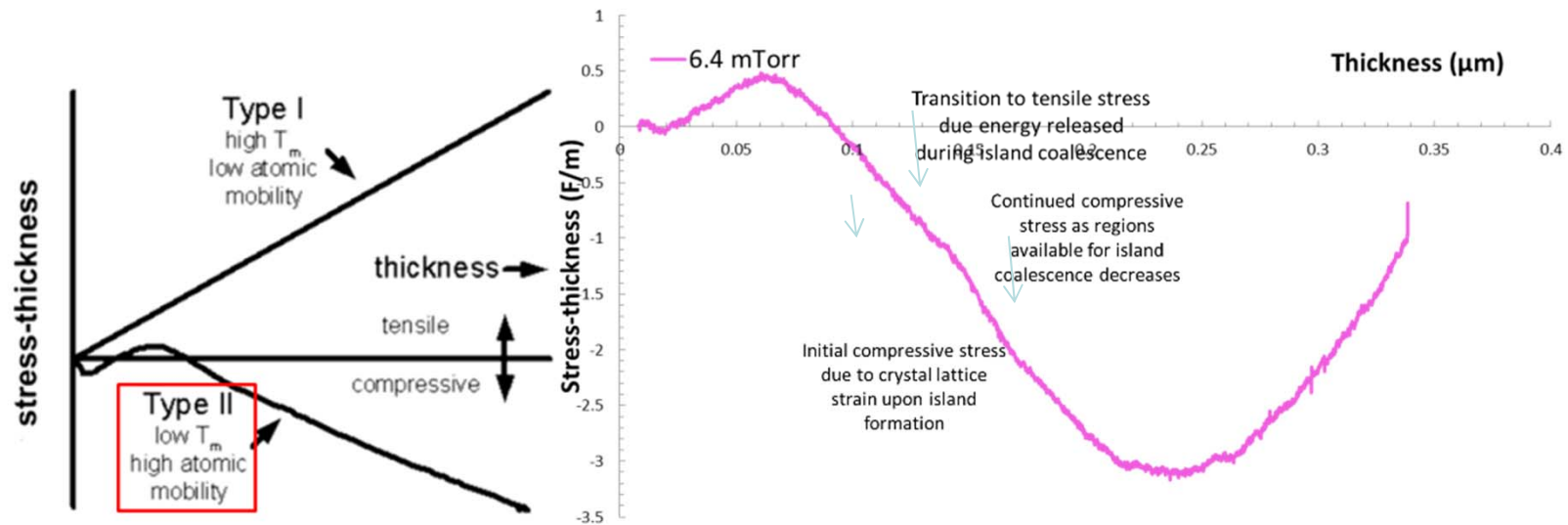
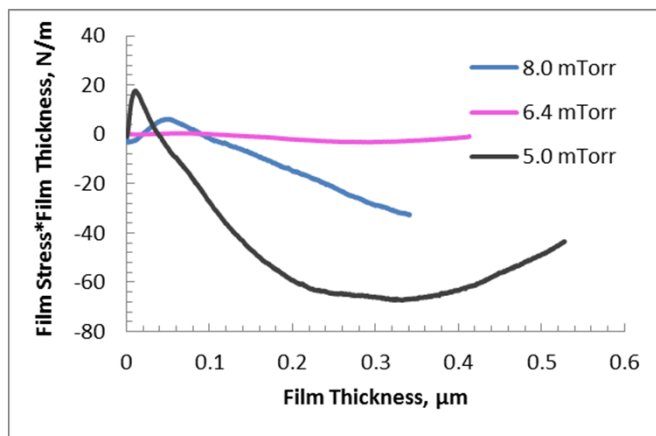


Figure 1- After R. Abermann, *Vacuum* 41, 1279 (1990) (left); Measured In-Situ (right)- Data matches measured curves from several published experiments.



- The stress can be controlled by varying the Ar pressure
- The deposition rate has to be taken into account.
- In-situ stress monitoring during the deposition process is being pursued.

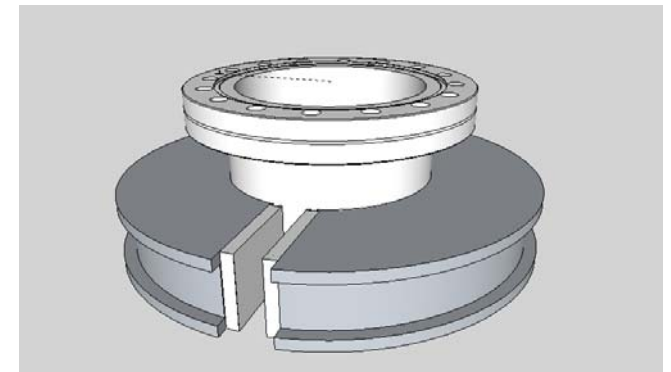
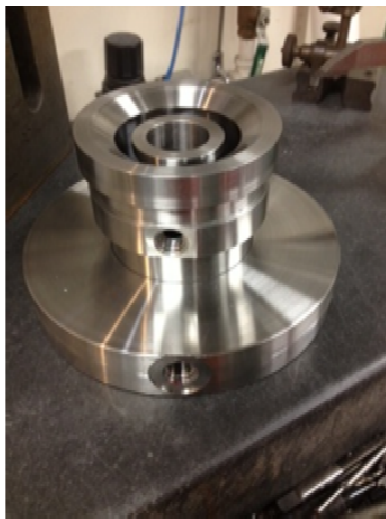


Stress Measurement in Coatings



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- o The probe tip can detect changes as small as 5nm under ideal conditions (i.e. in very low noise environment)
- o Typical background noise during a two hour deposition process is about 0.5 micron. This corresponds to a minimum stress that can be measured of a few MPa for a substrate thickness of 350 micron
- o However, the signal to noise can be improved for a given stress value by decreasing the thickness of the wafer.
- o Largest source of noise is due to thermal expansion of critical components resulting from temperature variation in the lab and during the deposition process.
- o The unwanted effects are being mitigated through the fabrication of water cooled components
- o **Stress measurements as low as a few Pascals may be in reach.**

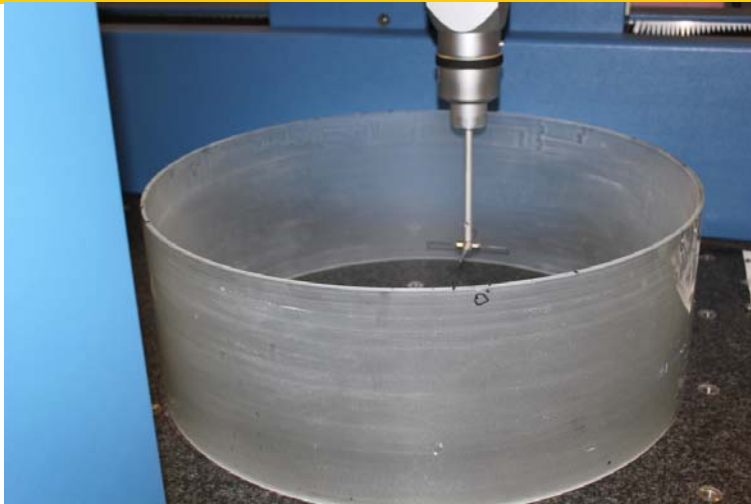




Deterministic Polishing

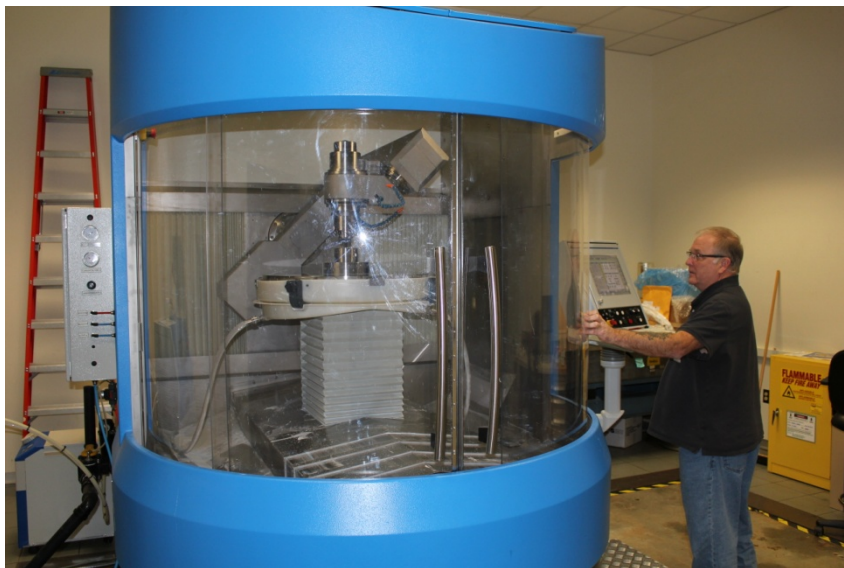


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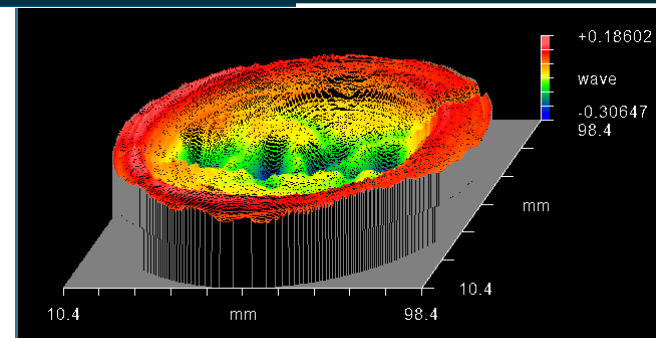
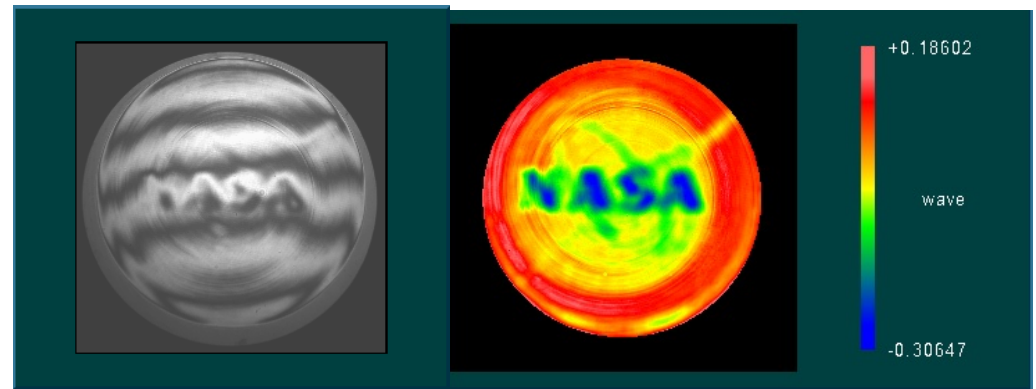


5-mm thick, 0.6 m diameter glass shell after grinding

- Thin-wall-full-shell “Chandra-like” optics;
- Goal is 1-2 mm thick, meter-class full shell mirrors;
- Take advantage of modern robotic polishing/grinding machines;
- Metrology/fabrication support fixtures are under development.



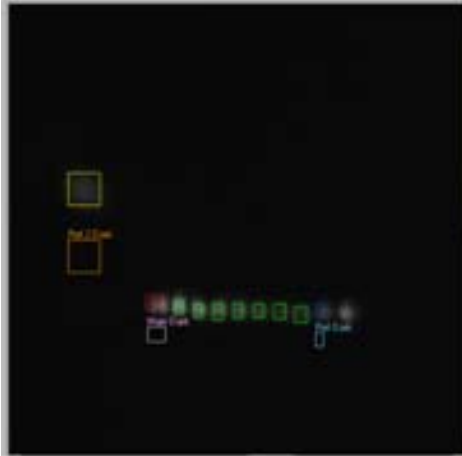
Zeeko machine at MSFC



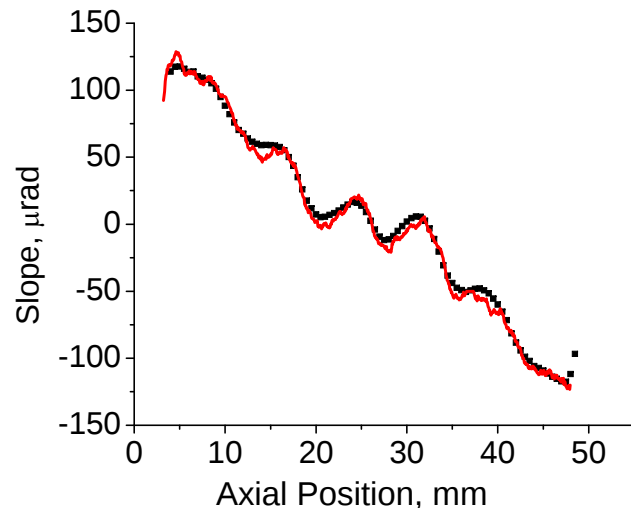
NASA logo polished into the 50 mm diameter glass flat



Sub-Micro-Rad Metrology

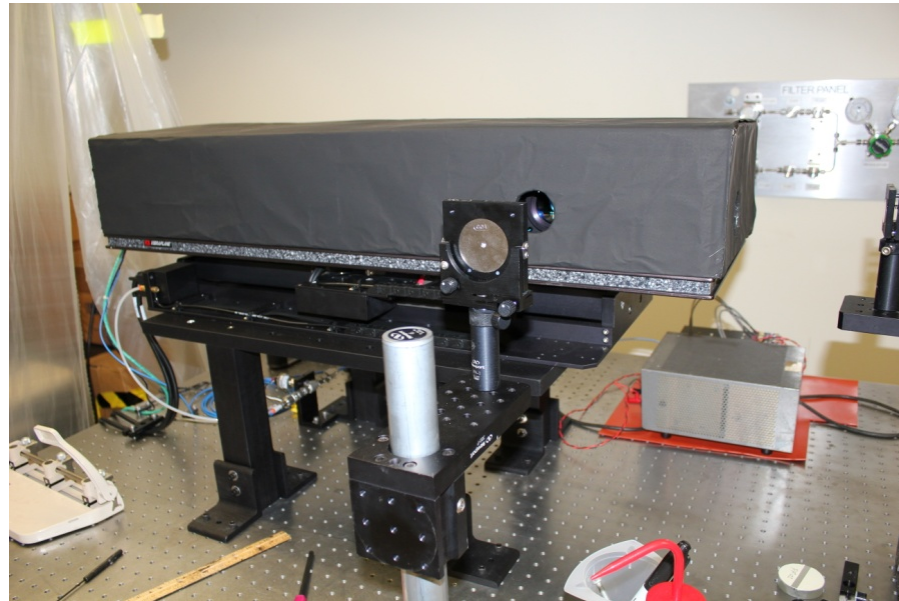


MBLTP: Ten signal and one reference beams on the detector



Red – Zygo interferometer, Black - MBLTP

- To achieve the sub-arc-sec x-ray optics the resolution of the figure metrology has to be at sub micro-rad level
- State-of-the-art for Long Trace Profilometer (LTP) is 0.2 microrad
- LTP measures the surface slope directly using a single laser beam. The change of laser spot position on the detector is directly proportional to the change in the surface slope.
- Multi-Beam Long Trace Profiler (MBLTP) is developed to increase the speed of measurements



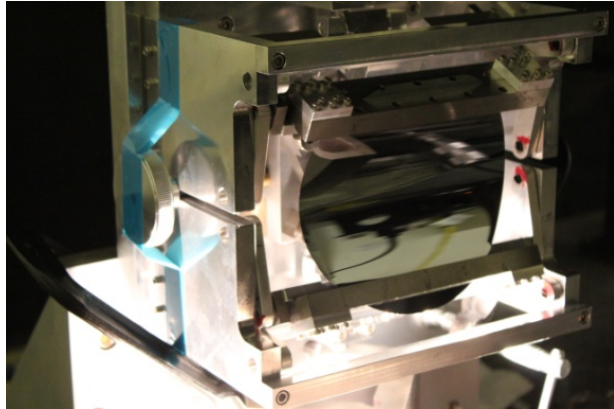
Multi-beam Long Trace Profilometer developed at MSFC



Can Bendable X-ray Optics be Applied for Astrophysical Applications?



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150 μm thick wafer cylindrically bent to 0.25 m dia



Wafer bender

In synchrotron world the diffraction-limited angular resolution has been achieved using bendable x-ray optics:

- The use of torque bending
- Metrology and, hence, fabrication of perfect flat surface (better than 0.5 micro-rad rms) is straightforward. The substrates are affordable, but they are relatively thick – few mm.

Approach is to start the x-ray mirror fabrication process with naturally-flat, thin silicon wafers and form them through torque bending and differential deposition into very-light-weight, sub-arcsecond-resolution mirrors ready to be installed into a telescope structure.

To date:

- The stresses and the resulting surface deformations in Si-wafers have been simulated. The deformations are low frequency and in the range correctable by differential deposition.
- The simulation results for the deformations are confirmed by experiment
- The bender is designed and a model has been printed.
- The experiments to form the parabolic surface on the flat substrate by differential deposition are in progress.



THANK YOU



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Questions?